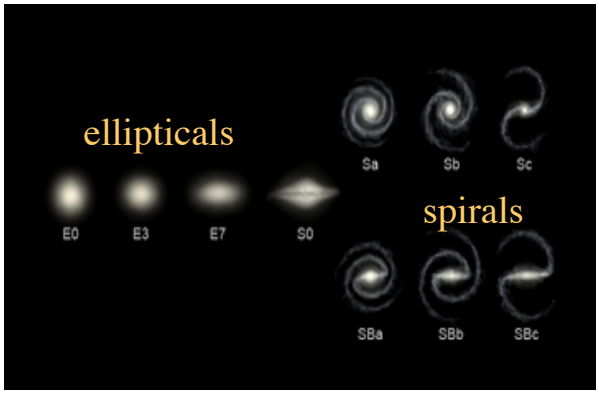
Galaxies- **Please Read CH 1 in S+G**

- What is a galaxy?
  - Observationally
  - Theoretically
- Observationally
  - A lot of matter in 'one' place
    - historically matter was traced by optical light (due mostly to stars)
    - Now can find and study galaxies by radio and mm emission from ionized gas, IR emission from dust and by x-ray emission from their ISM+ black holes
- Theoretically
  - A bound system with a *mass* between that of a globular cluster (~10^6 $M_\odot$ and a group of galaxies ~10^{13} $M_\odot$)
  - Most of the mass (>65%) is dark matter (>10x more DM than stars)
    - **e.g. compact condensation of baryons near the center of dark matter halos.**



Galaxies come in a huge range of shapes and sizes
Generically divided into 3 generalized morphologies

spirals
ellipticals
irregulars

Welcome!

- What is this course about?
- Logistics
  - Textbook, web pages
  - Pre-requisites
  - Assignments, exams, grading
  - Academic integrity
  - Semester plan
- Discussion
  - galaxies the big picture

Textbook & web pages

- Required text: Galaxies in the Universe: An Introduction (2nd Edition) by L. Sparke & J. Gallagher Authors' web page

http://www.astro.wisc.edu/~sparke/book/galaxybook.html

- Secondary book: Galaxy Formation & Evolution (very complete but dense) Mo, van den Bosch and White

http://www.physics.utah.edu/~vdbosch/astro5580.html

- the first two chapters of MBW are on-line at

http://www.astro.umass.edu/~hjmo/astro330/htmldir/reading.pdf

For reference

Galactic Dynamics (2nd Edition) by J. Binney & S. Tremaine

Course web page:

  - Information, syllabus, lecture schedule
  - Assignments
  - Past lectures
- Lectures will be posted on the web page *after* they are given

Other books

Extragalactic Astronomy and Cosmology: An Introduction by P. Schneider

A good second reference for this course. The book contains a good and up-to-date description of all key concepts in extragalactic astronomy and cosmology, but does not delve too deeply into mathematical formalisms and proofs

Secondary books

Galaxy Formation & Evolution by H. Mo, F. van den Bosch & S. White

upper-level textbook which presents an in-depth discussion on all topics of relevance for the formation and evolution of galaxies

Galactic Dynamics (2nd Edition) by J. Binney & S. Tremaine

An excellent textbook for topics related to the collisionless dynamics of galaxies, galaxy clusters, globular clusters and dark matter haloes

Galactic Astronomy by J. Binney & M. Merrifield

This textbook focuses mostly on observational aspects of galaxies and is out of date

The Structure and Evolution of Galaxies by S. Phillipps

Excellent textbook at the introductory level (John Wiley & Sons,Ltd, 2005; ISBN 978-0-470-85507-X, paperback).

Pre-requisites

- Mathematics
  - High-school algebra, trigometry , geometry calculus
- Familiarity with astronomy at ASTR300 level
  - Course will be fairly self-contained
  - I will use basic astronomy terms freely (e.g. star, planet, galaxy), and will cover some topics quickly
  - We will try to follow the text, but ...
  - Please ask about anything when you are unsure or I am not clear !

Letter grades

- Grading by:

Letter grade	Percentage
A	86-100
B	70-85
C	60-69
D	40-59
F	0-39

- I will adjust exam scores for a median of ~75% (low B) *if necessary*
- This means that homework is important!

Assignments & Grading

- Assignments:
  - Homework: 25%
  - Midterm : 20%
  - Final : 35%
  - Project/term paper 20%
  - TOTAL : 100%
  - *Class participation is encouraged*

  - *Mid-term date March 16*

Homework

- Homework assigned approx. once every two weeks
- HW is collected *at the start of class* on the due date (a week later)
  - **Please hand in on time**, or document the valid reason why it is late.
  - No credit after the day on which it is due, unless there is a justifiable reason.

ASTR421:Galaxies

Prof. Richard Mushotzky
Room PSC 1111Phone: 301-405-6853
Email: richard@astro.umd.edu
Office hours: 10:00-11:00am Tues/Thurs- TBD by appointment

75 min class
web pages see YY

Mid-term March 16

Term paper May

Please No open laptops Or Use Of Cell Phones During lectures

Other Info- Academic calendar http://www.provost.umd.edu/calendar/17.cfm

- In event of a REAL EMERGENCY which forces you to miss an exam
  - Contact me prior to the exam- or as soon as possible
  - Document the emergency
- March 11 is last date to drop with a W
- Spring break March 19-26
- Last day of classes May 11

Emergencies
Based on University Policy

- Regular attendance and participation in this class is best. However, if a class must be missed due to an illness, or other valid reason, the policy is:
  - For every necessary absence from class, a reasonable effort should be made to notify me or the TA in advance of the class. When returning to class, students must e-mail me or bring a note identifying the date of and reason for the absence.
- If a student is absent more than 5 time(s), documentation signed by a health care professional may be requested.
- If a student is absent on days when **tests are scheduled**, they should notify me in advance (if possible), and upon returning to class, bring documentation of the illness or personal reason.
- Please inform me of any other issue requiring special attention

Academic integrity

- **Always:**
  - Present your own thoughts in your own words
  - Cite any references that you use
- **Never**:
  - Copy from another student
  - Directly quote any published article unless you also give full credit to that article.
  - Allow other students to copy from you.
- Per campus policy, please write the honor pledge on each assignment

Syllabus

Lecture #	TOPIC	Text Chapter
Lec 1	**INTRODUCTION**	
Lec 2	Continuation of introduction	Ch 1
Lec 3	Basic Galaxy Properties	Ch 1
Lec 4,5	Relevant Properties of stars	
Lecs 6,7,8	Properties of Gas and Dust	
Lecture 9, 10	Milky Way Ch 2 in S+G	
Lecture 11	Galactic Rotation	
Lecture 12---15	Dynamics I---III Chap 3 of S&G	
Lectures 16,17	Local group Ch 4 of S&G	
Lecture 18	Chemical Evolution	
Lecture 19	Star Formation	
Lecture 20---22	Spiral Galaxies Ch 5 of S&G	
Lecture 23---25	Elliptical galaxies Ch 6 of S&G	
Lecture 26---28	AGN I---III Ch9 of S&G	
Lec 29	Summary	
Lec 30	Questions	

- *Please read Chapter 1 of the book- for those of you who do not have the book, I will print out the first chapter. You can pick it up Friday or before the next class*
- First HW assigned Thursday next week

- **ASTRONOMY GENTLELADIES' NETWORK**
- **First Meeting: February 7th at 6:00 PM in PSC 1150 (graduate lounge) Get to know our new and returning members!**
- Meet the 1st Tues of each month
- Grad/undergrad-only events, refreshments provided
- **Monthly coffee breaks open to the whole department, meet the Colloquium speaker, coffee & breakfast food provided**
- 2nd Wednesday of each month, 10:30-11:30 AM

Topics we will cover

- Broad description of galaxies
- Stellar populations/star formation
- Gas and Dust in galaxies
- Milky Way as a detailed example of a galaxy
- Galactic dynamics/need for dark matter
- Spiral galaxies
- Elliptical galaxies
- Galactic evolution/formation and cosmological implications
- Active Galactic nuclei -galactic centers
- This is an **enormous** range of material; the level of detail will vary greatly from section to section

Recent Reviews:Advanced Stuff

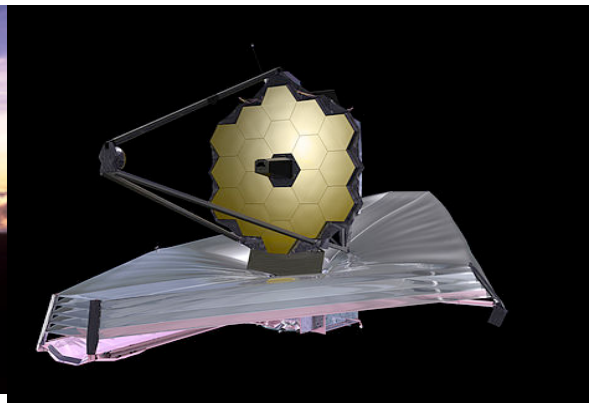
Physical Properties and Environments of Nearby Galaxies
ARA&A 47: 159 M Blanton and J Moustakas

Physical Properties of Galaxies from z = 2–4 ARA&A 49: 525 2011
Alice E. Shapley

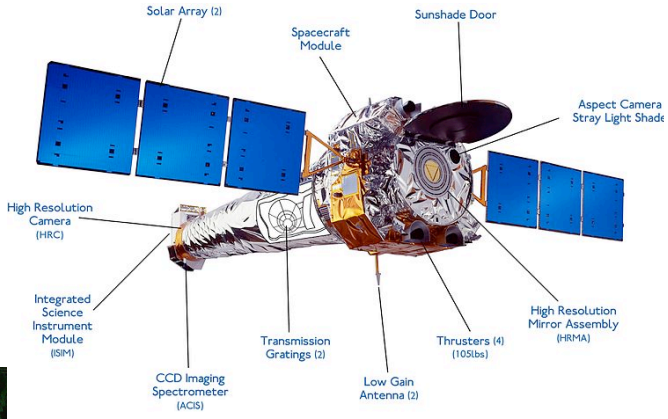
Physical Parameters Along the Hubble Sequence: M Roberts and M. Haynes
ARA&A Vol. 32 (1994): 115-152

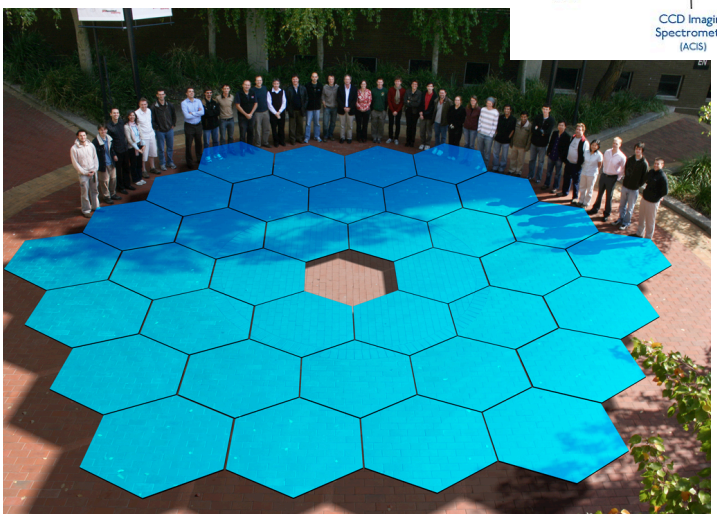
Star Formation In Galaxies Along The Hubble Sequence R. Kennicutt, Jr.
ARA&A Vol. 36 (1998): 189 - 231

Galaxy Formation: Where Do We Stand? Christopher J. Conselice arXiv: 1212.5641

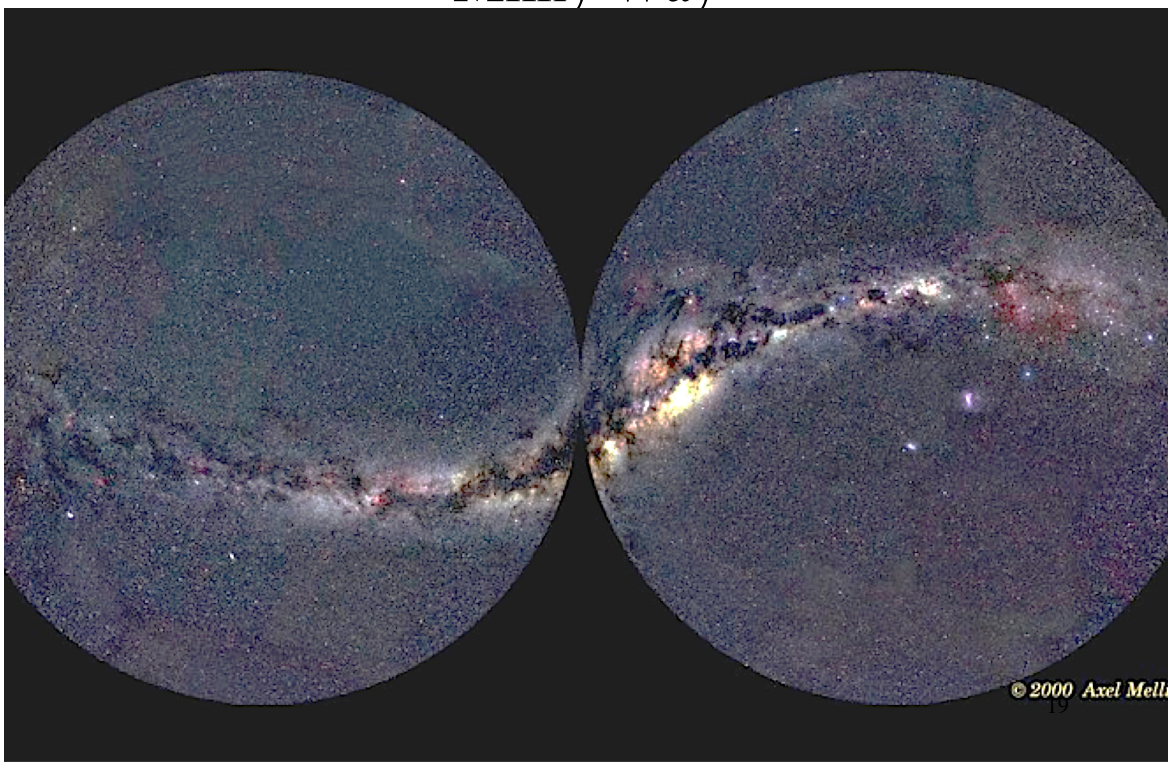


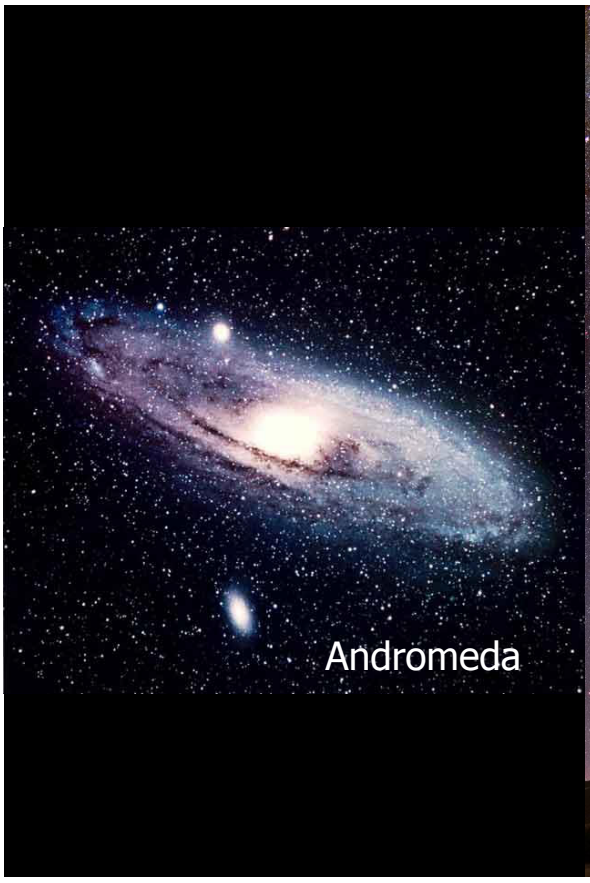
SOME OF THE TOOLS OF THE TRADE

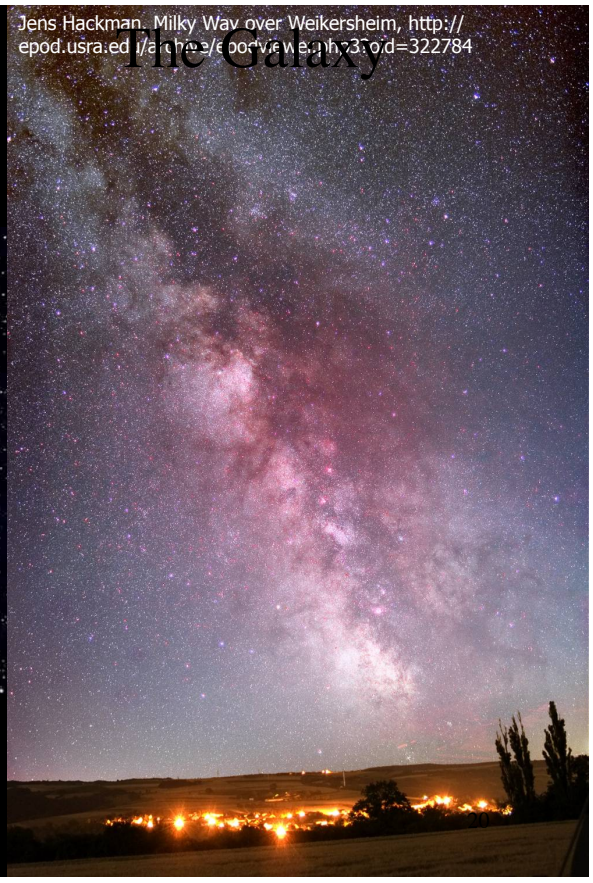


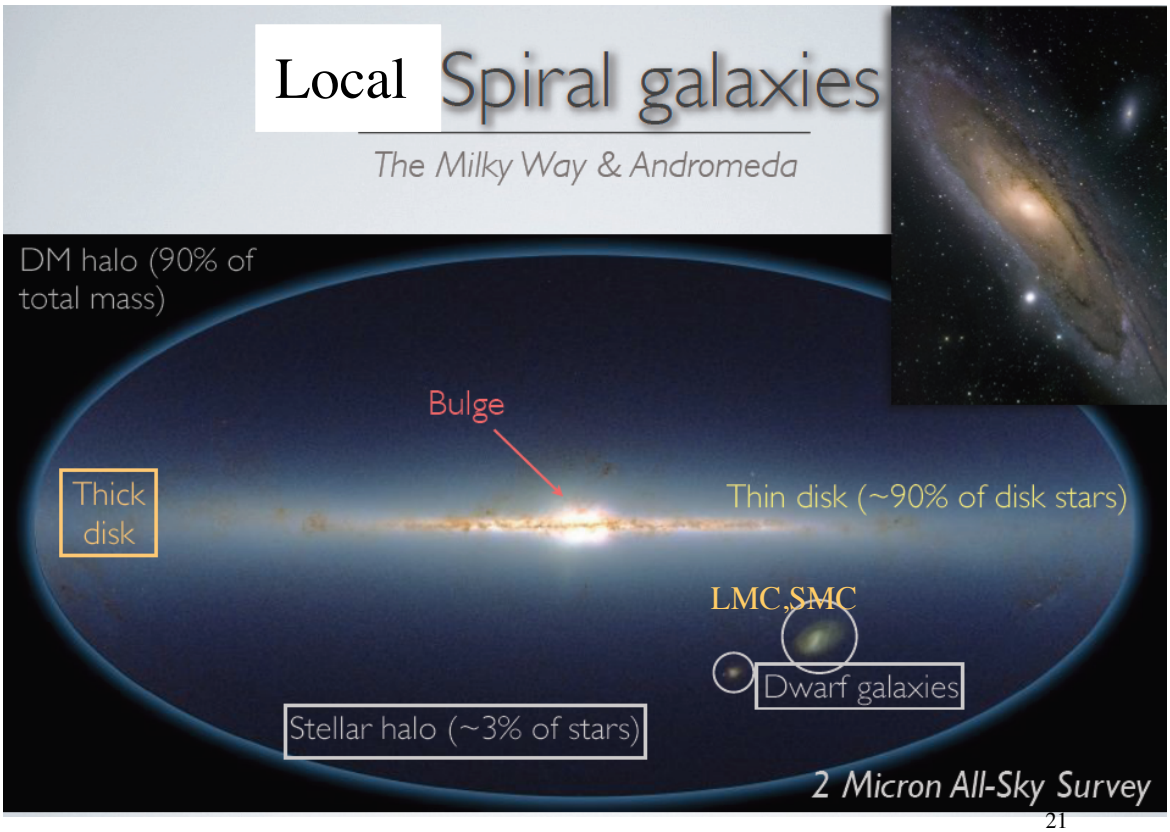


Optical Image of Sky- Dominated by the Milky Way








Local Spiral galaxies
The Milky Way & Andromeda
DM halo (90% of total mass)
Bulge
Thick disk
Thin disk (~90% of disk stars)
LMC,SMC
Dwarf galaxies
Stellar halo (~3% of stars)
2 Micron All-Sky Survey


Hubble space telescope Ultra Deep Field (S. Beckwith et al.)
The Universe

The BIG Picture

- Essentially, all research on galaxies aims at answering how galaxies form and evolve **and** the connection between dark matter and baryons
- Need to understand role of the different galactic structural components (e.g. *gas, dust, stars, dark matter*) and how they relate with each other and evolve over cosmic time.
- Link structural analysis, kinematics and dynamics, stellar population properties and evolution, multi-wavelength observations, ample redshift coverage, and theory. (Gadotti 2012)
- From a theoretical point of view Galaxies reside in dark matter halos*, but, are biased tracers* of the underlying matter distribution: that is the observable galaxy properties such as luminosity are not *simple* tracers of dark matter.
- Different kinds of galaxies reside in different mass halos and massive halos can host *multiple* galaxies (pairs, groups, clusters)

*** jargon warning**

Modern galaxy research

- Explain the observed galaxy population and its changes over cosmic time
- Understand why galaxies show the extreme regularity of various parameters
- Try to use galaxies to understand cosmology and vv.

Cosmic laboratories for **all the details of astrophysics**

- star formation
- formation of the chemical elements
- the relationship of black holes to their host galaxies
- nature and distribution of dark matter

What is galaxy research about?

- Explain galaxy population as consequence of initial conditions (+ stability arguments + feedback)
- Understand astonishing regularity of galaxy population
- Understand galaxies well enough to make them (even better) cosmological diagnostics
- Test of galaxy formation
- Have fun!

A Brief History

http://en.wikipedia.org/wiki/Galaxy#Observation_history

- Discovery of 'nebulae' in late 1700's (Messier) and their cataloging in the late 1800's (NGC catalog)
- Realization (Great Debate, Shapley, Hubble etc) that the nebula were outside the Milky Way- *island universes* (originally due to Kant)
- Expansion of the universe 1920's (Hubble)
- Dark matter- Zwicky 1930's Rubin 1970's
- Cosmic Microwave Background and Big Bang Nucleosyntheis established the Big Bang
- 1980's - the development of Cold Dark Matter (CDM) and post 1998- ΛCDM

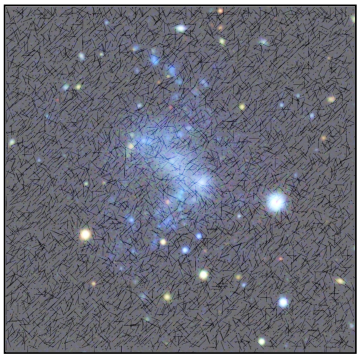
http://www.astr.ua.edu/keel/galaxies/history.html

Galaxies: From J. Dalcanton

The velocity (V) is characteristic of the the motion of stars/gas in these systems

M_{halo} is the mass of the dark matter potential well in which the galaxy resides

Clustering refers to how the objects are distributed in space



Ellipticals

$M_{halo}>10^{11}M_{\odot}$

V~350km/s

Highly Clustered

Old stars

little star formation *now*

Spirals

$M_{halo}>10^{10}M_{\odot}$

V~200km/s

wide range of stellar ages

star forming *now*

Dwarfs

$M_{halo}>10^{8}M_{\odot}$

V~30km/s

Weakly Clustered

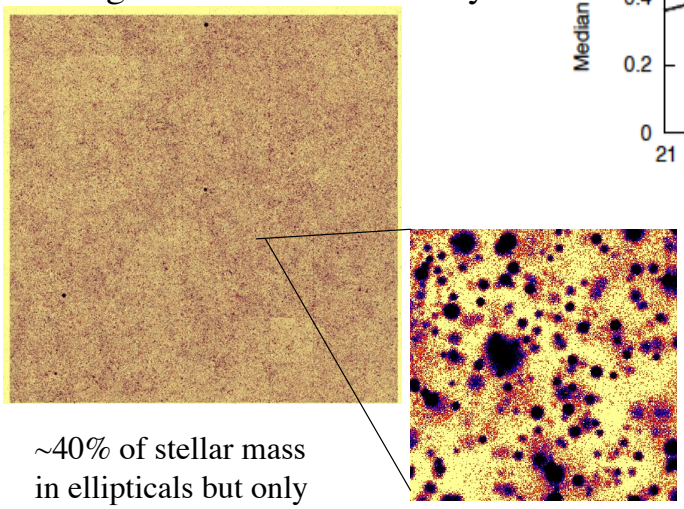
Young stars

Numerous

How Many Galaxies are There?

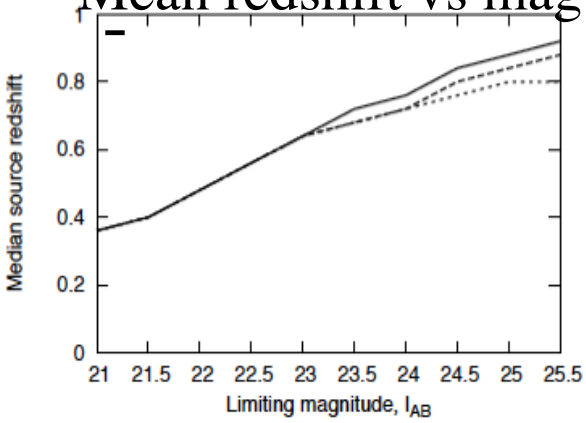
~50 galaxies/sq arc min at m~25.5, rising slowly to ~175 at m~29

The median redshift at a given magnitude increases slowly

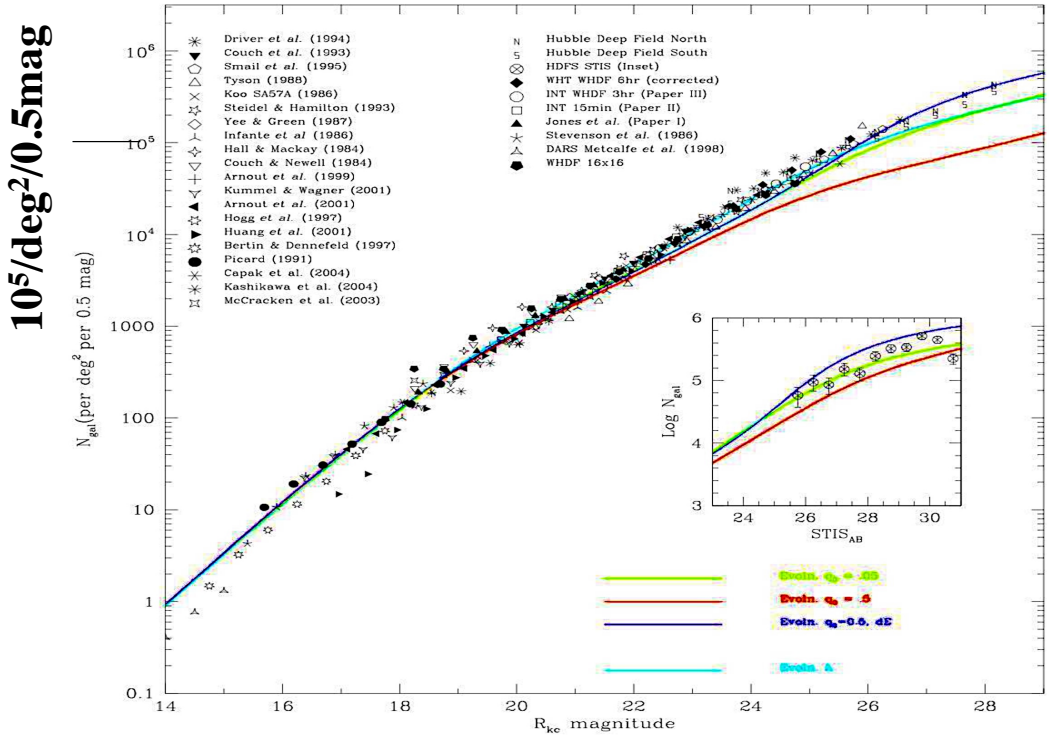


~40% of stellar mass in ellipticals but only 5% by number

Mean redshift vs mag

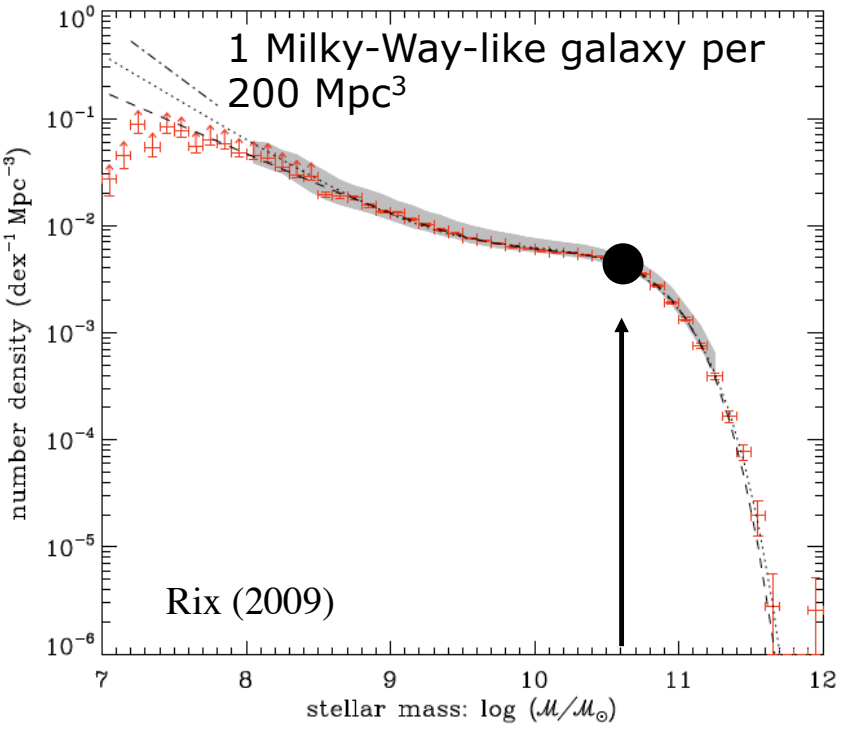


Galaxy surface density vs mag



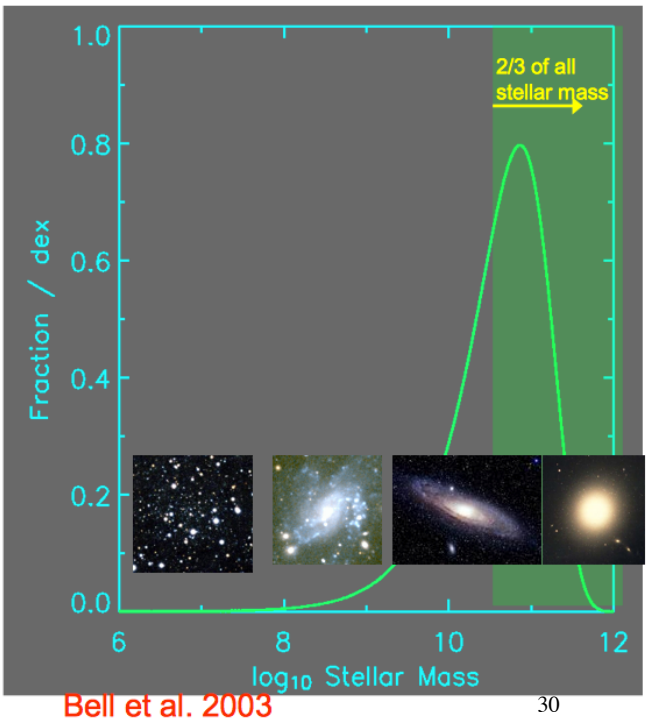
magnitudes

- The Number function of galaxies (#/volume)



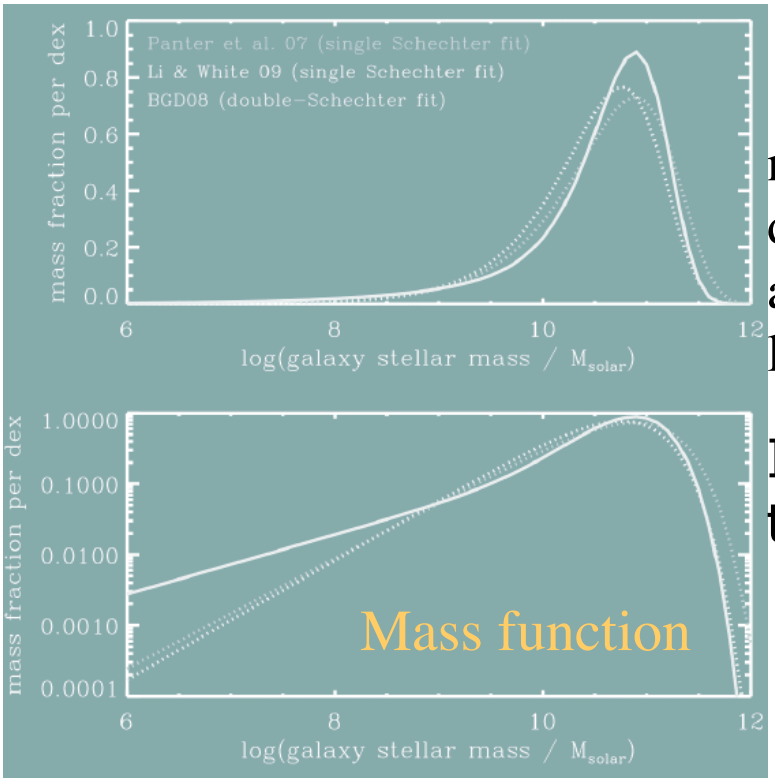
Galaxies Have a Wide Range in Mass

- There is a range of **~10^8** in galaxy masses- but most stars reside in galaxies in a narrow mass range ~6+/-3x$10^{10}M_\odot$ (in stars)- certain types of galaxies tend to live in certain mass ranges.
- The baryons are distributed in gas, stars and dust; wide range in gas/stars, relatively narrow range in dust/gas.



Bell et al. 2003

Where is the mass-



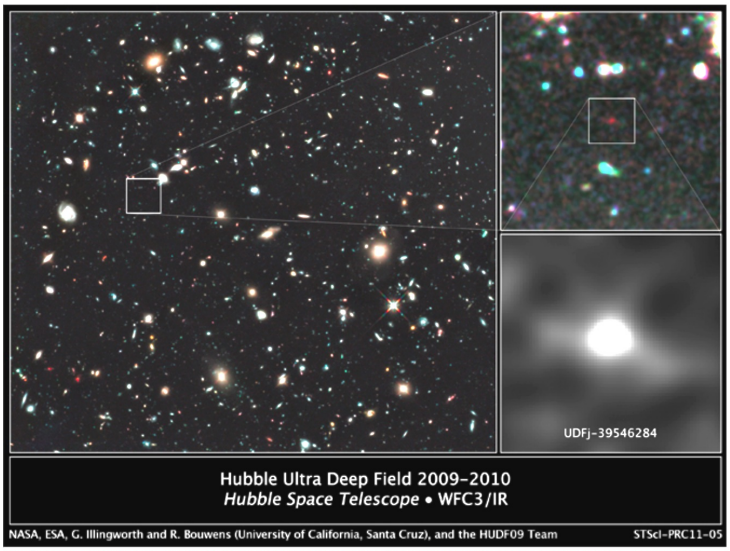
narrow distribution around $\log M_{star} \sim 10.5 M_{\odot}$

In mass MW is typical

How Old are Galaxies

- HST imaging of galaxies at z~9 (13.17 Gyrs age, for an age of the universe of 13.72 Gyrs)
- Stellar ages: in MW oldest stars are ~13.2 Gyrs old (error of +/-2 Gyrs) (Physics Today, vol. 65, issue 4, p. 49)
- However galaxies have changed enormously over cosmic time
- The present day pattern of galaxies emerged at z~1

(z is the redshift and for a given cosmology there is a straightforward relation between distance, age and z)

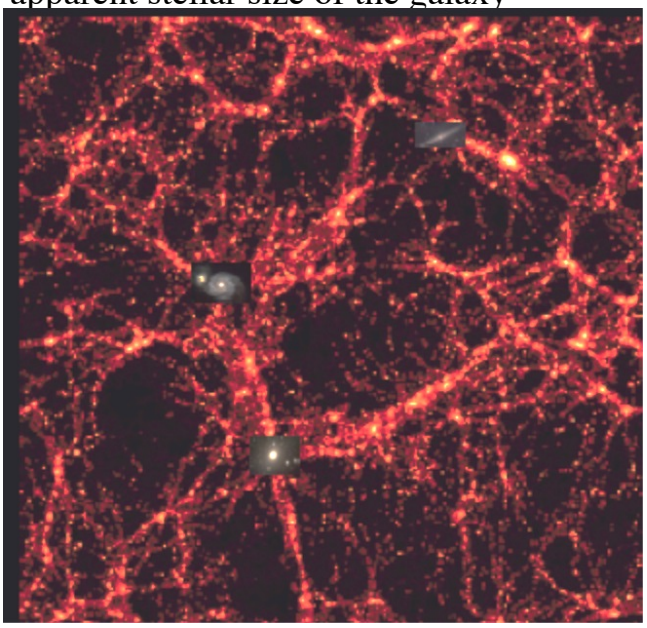


The farthest and one of the very earliest galaxies ever seen in the universe appears as a faint red blob in this ultra-deep-field exposure taken with NASA's Hubble Space Telescope. This is the deepest infrared image taken of the universe. Based on the object's color, astronomers believe it is 13.2 billion light-years away. (Credit: NASA, ESA, G. Illingworth (University of California, Santa Cruz), R. Bouwens (University of California, Santa Cruz, and Leiden University), and the HUDF09 Team)

http://www.astro.ucla.edu/~wright/CosmoCalc.html

Galaxies Do Not Live Alone

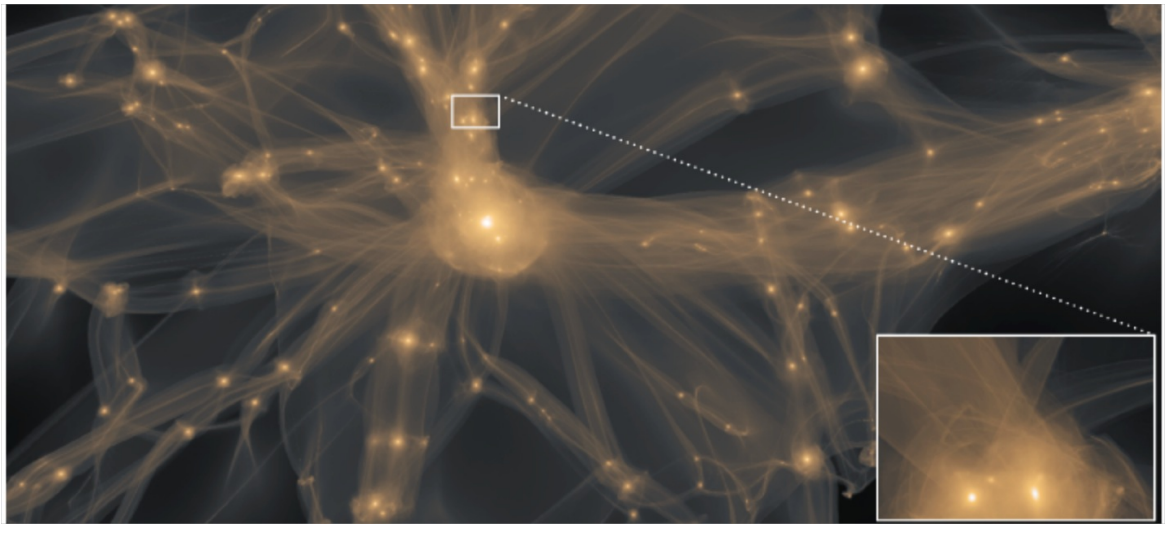
- Galaxies are part of the 'cosmic web'- representing over dense regions of baryons **and** dark matter
- The effective size of the **dark matter halo** is much larger than the apparent stellar size of the galaxy



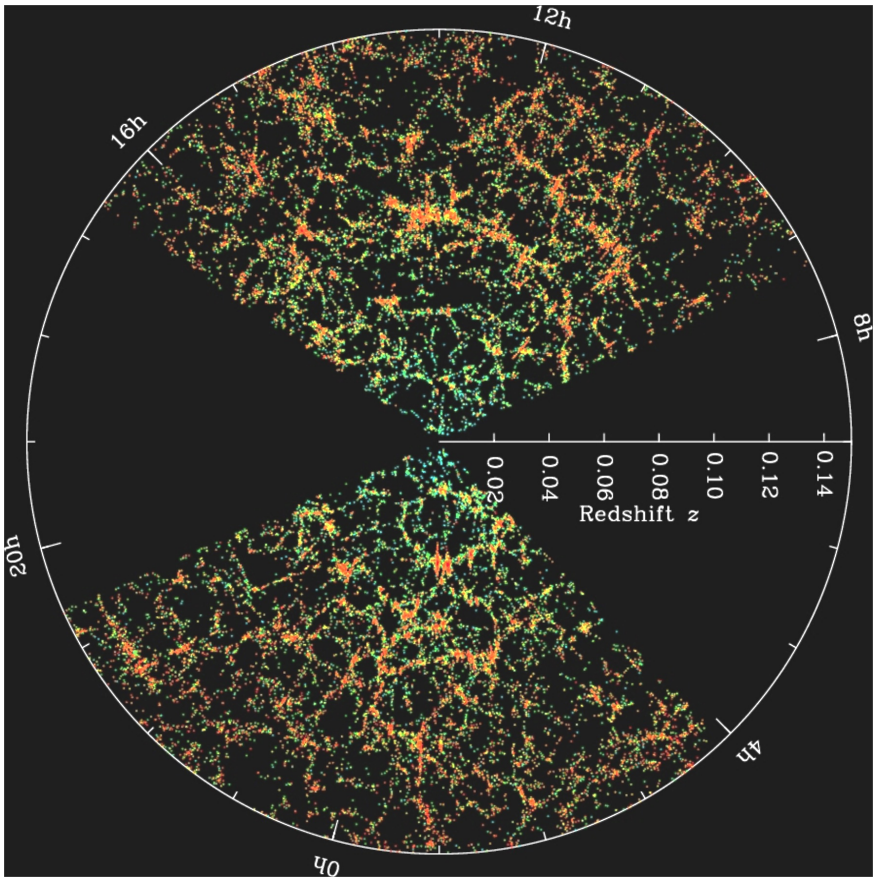
The cosmic web has structure at all scales but eventually becomes homogenous at scales >70Mpc

Eric Bell

Cosmic Web- Numerical Simulation



In this rendering the large scale sheets and filaments are more easily seen- galaxies tend to reside in these sheets and filaments and are rare in voids.

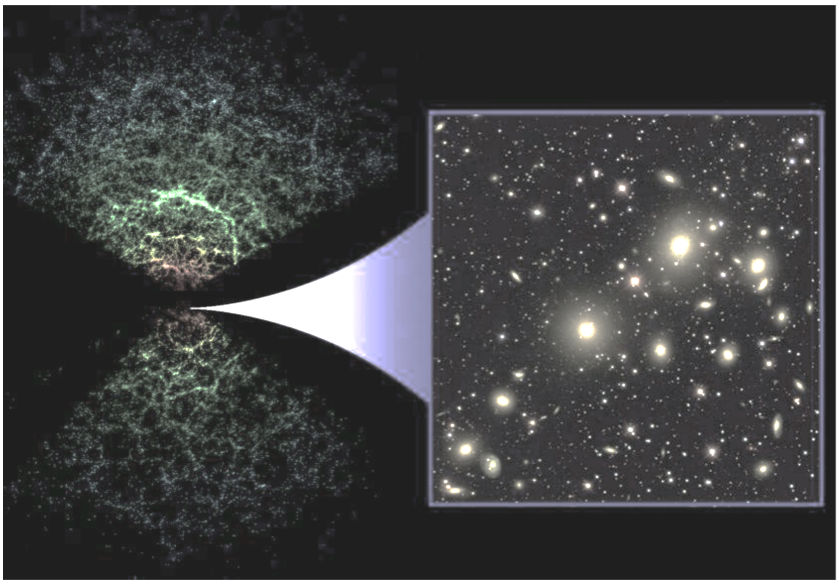


Sloan Digital Sky Survey

Galaxies color coded by the age of their stars
red= old
blue=young
http://www.sdss.org

Large Scale distribution of galaxies

- On scales $<10^8$pc the universe is 'lumpy'- e.g. non-homogenous
- On larger scales it is more homogenous- and isotropic



Sloan Digital Sky Survey- http://skyserver.sdss3.org/dr8/en/